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TECHNICAL MEMORANDUM No. 13/M/48

PICATINNY ARSENAL  
SCIENTIFIC AND TECHNICAL INFORMATION BRANCH

The Suitability of the Oxidants Liquid Oxygen,  
Hydrogen Peroxide and Nitric Acid in Liquid  
Propellant Systems for Operational Use

REVIEW ON Oct. 78

L. A. Wiseman

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The Suitability of the Oxidants Liquid Oxygen,  
Hydrogen Peroxide and Nitric Acid in Liquid  
Propellant Systems for Operational Use.

by

L.A. WISEMAN.

L5

This memorandum contains material of overseas origin.

Oct 1948  
L6

WALTHAM ABBEY,  
ESSEX.

OCTOBER, 1948.

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3. Hydrogen Peroxide
4. Liquid Rocket Oxidizers
5. Oxygen

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Table of Contents.

- 1) Introduction
  - 2) Performance
  - 3) Storage and Transport
    - (a) Liquid Oxygen
    - (b) H.T.P.
    - (c) Nitric Acid
  - 4) Operational Supply
    - (a) General
    - (b) .Naval
    - (c) Land
    - (d) Air
  - 5) Hazards
    - (a) Explosive Risks
    - (b) Fire
    - (c) Toxicity
  - 6) Requirements for Individual Weapons.
    - (a) Long Range Strategic Weapons
    - (b) Short Range Strategic Weapons
    - (c) Anti-Aircraft Weapons
    - (d) A.T.O's
    - (e) Aircraft Boosts
    - (f) Underwater Propulsion
  - 7) Availability
  - 8) Conclusions
- Two Tables.



## 1) Introduction.

General reviews of these three oxidants have been issued (Refs. 1 & 2), but in neither of these reports was there a discussion of their suitability for specific operational uses. Subsequent to these reports, an assessment of the most suitable of these oxidants for A.T.O's and aircraft boosts (3) was issued. With a fuel, such as kerosine, there is little difference in performance between these oxidants and therefore the assessment can be separated broadly into two parts, viz: operational requirements and availability.

The term operational requirements has many different aspects and includes such questions as handling and storage properties, hazards in use, etc. It should be realised that the fact that a chemical is a vigorous oxidant implies that it will react under some conditions with anything that can be oxidised, that is, with many ordinary materials. Although the degree of this reactivity varies, it is clear that such chemicals must always present difficulties in handling.

Availability must be analysed from several viewpoints. The first is whether it can be produced in large quantities and, if so, whether the particular advantages of a given oxidant justify its production. Fortunately in the three oxidants under discussion this question is easily answered. Both liquid oxygen and nitric acid are already manufactured on the large scale and the problem here is whether the quantities required for liquid propulsion systems will be compatible with other requirements. In the case of Hydrogen Peroxide, there is one operational requirement - for underwater propulsion - in which Nitric Acid and liquid oxygen are not practical alternatives, and therefore it can be assumed that there will be some large scale production in the U.K. The question is thus whether the production planned can meet the total requirements.

Although these three oxidants are normally considered to be the only ones likely to be available in the near future, it should be realised that liquid Nitrogen Dioxide is potentially available in large quantities as an intermediate in the production of Nitric Acid.

Finally the three oxidants should be more closely specified. The only impurity in liquid oxygen is a trace of nitrogen, but both Nitric Acid and Hydrogen Peroxide (High Test Peroxide, H.T.P.) as used commercially require closer definition. By Nitric Acid is meant 98%  $\text{HNO}_3$  (+ 2% water and possibly traces of  $\text{NO}_2$ ) which will be referred to as White Fuming Nitric Acid (W.F.N.A.). Much work in America has been carried out with Nitric Acid containing Nitrogen Dioxide in solution. This is called Red Fuming Nitric Acid (R.F.N.A.). Either acid may also contain various metallic salts to catalyse ignition, or small amounts of Sulphuric Acid (up to 10%) for reducing its corrosive properties. The Nitric Acid, referred to in this report, is 98%  $\text{HNO}_3$  i.e. W.F.N.A. Hydrogen Peroxide, as used for propulsive purposes, generally contains 80% to 90%  $\text{H}_2\text{O}_2$ , and H.T.P. is usually defined as 85%  $\text{H}_2\text{O}_2$  with the addition of stabilisers.

## 2) Performance.

The comparative performance of the three oxidants has been discussed many times. With a combustion chamber pressure of 300 lb/sq.in. and with kerosine as fuel, W.F.N.A. and H.T.P. have a

/Specific



Specific Impulse of about 220 secs., while liquid oxygen gives about 240 secs. In many applications, however, the performance per unit volume of propellant is more important and, assessed on this basis, W.F.N.A. and H.T.P. (kerosine fuel) are about 20% better than liq. O<sub>2</sub> because of their higher density.

These conclusions are generally true for any normal fuel e.g. hydrocarbons, alcohols. If, however, liquid hydrogen is the fuel, then under the same conditions as above, W.F.N.A. and H.T.P. give S.I.'s of about 285 secs. (Ref.4), while liq.O<sub>2</sub> has an S.I. of approx. 340 secs. This is a rather greater difference in performance and, as liq.H<sub>2</sub>, would be used only when volume, i.e. density, was not a controlling factor in weapon design, it follows that liq.O<sub>2</sub> would be preferred in such a case. A brief table of physical properties is given at the end of this report.

Finally it should be mentioned that the combustion temperature with H.T.P. is about 300°C. below that of the other oxidants for equal performance. This factor is of importance when the temperature resistance of the constructional material must be considered. However, any high performance rocket motor with a time of operation greater than a few seconds must be regeneratively cooled. If kerosine is the fuel, the oxidant would be used as the coolant in preference, as kerosine has poor thermal properties. Both HNO<sub>3</sub> and H.T.P. have been used as coolants in regeneratively cooled motors. Liquid Oxygen has been used to cool a rocket motor but much more work is necessary on this problem. On grounds of stability, HNO<sub>3</sub> is better than H.T.P.

### 3) Storage and Transport.

#### (a) Liquid Oxygen.

Storage of liquid oxygen is only practicable for relatively short times, unless production facilities are available to maintain the supply. It can be stored in copper, aluminium or in special steels, the main problem being the selection of metals which retain their strength at the temperature of liquid oxygen. Such vessels are thermally insulated by lagging, large Dewar vessels being too expensive and heavy. Small compact low-pressure plant for liquid oxygen production is under development and the requirements for liquid oxygen at operational bases could be met by this means. The losses on storage amount to about 2% per day, roughly, which means that a storage capacity of 100 tons could be maintained by the output of a small low pressure plant which would replace evaporation losses. The main losses occur in the transfer from one vessel to another. The Germans experienced losses of 50% between manufacture and filling into V.2's (Ref.3). Storage under tropical conditions offers no greater problems than storage under temperate conditions, the only difference being a greater evaporation loss.

The use of liquid oxygen away from production centres thus necessitates correctly designed storage tanks (the design of these is well understood), and small low pressure liquid oxygen plant. It is estimated that the production of each pound of liq.O<sub>2</sub> requires about  $\frac{1}{2}$  lb. of fuel oil, thus liquid oxygen storage requires a certain amount of capital outlay but is easily and cheaply maintained.

Transport of liquid oxygen is practicable by road or rail and suitable tank cars for both means are in current use. Storage

/on



Storage on board ship is feasible but the possible presence of high concentrations of oxygen gas makes the danger of fire very high and, in combat, this risk is considered to be too large, particularly as steel burns readily in liquid oxygen and a fire with liquid oxygen could involve the loss of the ship.

(b) H.T.P.

The Germans developed satisfactory means for the bulk storage and transport of H.T.P. and, under temperate conditions, the loss in concentration does not amount to more than 1% to 2% per year through decomposition. H.T.P. must be stored in tanks of pure aluminium cleaned by a simple but special technique. H.T.P. is stabilised (the preferred stabiliser in the U.K. is Sodium Stannate) against accidental contamination with very small quantities of catalytic impurities, but contamination with appreciable quantities of organic materials or many metals, generally compels dilution with large quantities of water and consequent loss of the H.T.P. Storage vessels for H.T.P. must always be vented and the most scrupulous cleanliness insisted upon. Movement during storage, as in transport and on board ship, does not of itself lead to larger losses in concentration in temperate climates (Ref.6).

For use in submarines the maximum temperature requirement is (at the moment) stability at 40°C (104°F). Experimental work on this aspect of storage is at present in progress at E.R.D.E. If stability in storage at higher temperatures is demanded, then it is probable that a time limit on the storage will have to be given but there seems no reason why the storage temperature should not be maintained at some acceptable value, e.g. by refrigeration in tropical climates. The effect of motion on stability at these higher temperatures has not been investigated and clearly work must be done on this aspect.

The freezing point of H.T.P. is about -20°C. (-4°F) and arctic conditions would create storage problems. The freezing point can be lowered by addition of certain compounds, the most promising of which is Ammonium Nitrate, but these difficulties could be overcome by suitable heating arrangements both for bulk storage and magazine storage of filled weapons. In operational use, however, under arctic conditions or in high flying aircraft or rockets, trouble may arise from the relatively high freezing point. Thus in trials with the Vickers Rocket-Propelled Aircraft Model at 35,000 ft. the temperature is near to the freezing-point of H.T.P. and, in fact, difficulties in starting were experienced which may have been due partly to the increased viscosity of the H.T.P.

On board ship contamination with chloride ions occurs by breathing in of air-borne sea-spray, the effect of which is to cause corrosion of aluminium by H.T.P. A concentration of nitrate ions (Sodium Nitrate) of about 10 p.p.m. has been found to inhibit corrosion by chloride, but more work on this aspect is necessary.

(c) Nitric Acid.

Nitric Acid (W.F.N.A.) can be stored without difficulty in vessels of pure aluminium, as long as the concentration is kept above 96% HNO<sub>3</sub>. At lower concentrations it readily attacks aluminium but, under these conditions, stainless steel is very resistant. At concentrations above 96%, stainless steel is slowly attacked but is adequate for short times of storage. Mild steel

/is



is also suitable for brief storage, particularly with the addition of certain inhibitors, such as phosphoric acid. It may well be that other aluminium alloys possessing greater mechanical strength than pure aluminium, may also be suitable. Work on these problems is in progress at E.R.D.E. The German firm of B.M.W. claimed to have carried out satisfactory storage trials with 98%  $\text{HNO}_3$  containing iron salts in sealed vessels of Duralumin (5) for periods up to one year (the alloy contained 3% of copper).

If aluminium vessels are used for storage of  $\text{HNO}_3$ , precautions must be taken to ensure that the concentration does not fall below 96%. In tropical countries the breathing cycle in tanks, fitted with breathing devices, will cause relatively large movements of air into and out of the tanks, and they must therefore be fitted with water traps. An alternative is to use completely sealed tanks and this should be quite practicable.

Transport of  $\text{HNO}_3$  is normally in sealed drums. There is at present no road vehicle which is approved by the Home Office, but Nitric Acid was transported in road tankers between the R.O.F's during the war. The Americans also have approved types of road tanker. In general, storage and transport of  $\text{HNO}_3$  is simpler than for the other two oxidants.

$\text{HNO}_3$  melts at  $-42^\circ\text{C}$  ( $-44^\circ\text{F}$ ) and boils at  $+86^\circ\text{C}$  ( $187^\circ\text{F}$ ). It is quite easy to depress the freezing point of  $\text{HNO}_3$  to below  $-50^\circ\text{C}$  ( $-58^\circ\text{F}$ ), e.g. by the addition of iron salts, and thus weapons could be stored and used at lower temperatures than with H.T.P. At temperatures near the boiling point  $\text{HNO}_3$  dissociates to give various oxides of nitrogen but, as this is an equilibrium process, storage in sealed vessels would prevent it from proceeding far. There is insufficient knowledge of the corrosion behaviour of Nitric Acid at high temperatures and more information is clearly desirable. However, it is not anticipated that this will lead to storage difficulties given suitable choice of materials.

#### 4) Operational Supply.

##### (a) General.

The main requirement of a weapon, assuming satisfactory functioning, is that it should offer the least possible danger to the operators. The use of petroleum products involves a considerable fire risk, yet the Services employ them because satisfactory ways of handling have been developed. The three oxidants under discussion are admittedly dangerous if handled by unskilled personnel, but offer little trouble to trained personnel adequately supervised. It is clear, therefore, that a most important operational requirement is the training of personnel for handling these materials.

Nitric acid and H.T.P. can be handled by normal processes used for liquids. In filling tanks, forced feed through hose of suitable materials can be used. The Germans developed plastics for use both with  $\text{HNO}_3$  and H.T.P. A considerable amount of work on H.T.P. resistant plastics has also been done in the U.K. but much more is necessary to develop ones which will stand up to  $\text{HNO}_3$ . B.M.W. (Ref.5), when filling oxidant tanks with  $\text{HNO}_3$ , used an air return in order to prevent escape of the fumes of  $\text{HNO}_3$ , and in this way were able to avoid the use of gas masks. Liq. oxygen can be handled in similar fashion.

/It



It is clear from the previous section that Nitric Acid and liquid oxygen could comply with extreme requirements more easily than H.T.P. It should be mentioned, however, that in the case of liquid oxygen, the high humidities associated with some tropical conditions would considerably increase any difficulties due to water condensation, e.g. with moving mechanical parts.

(b) Naval.

Storage on board ship presents a major problem as accidents may lead to loss of the ship. For reasons mentioned in the previous section, storage of liquid oxygen on board ship is considered too hazardous and would also entail extra plant to maintain the stock of liq.O<sub>2</sub>. In the event of storage of HNO<sub>3</sub> or H.T.P. on board ship, either in bulk or in filled weapons, the main safety requirement is the provision of plenty of water. Both these oxidants can be rendered innocuous by dilution with water and arrangements should be made for the immediate disposal of the diluted oxidants. It would be advantageous to be able to cover the floor of the magazine with water so that, in the event of rupture of containers, the fuel and the oxidant could not accumulate. This would be in addition to the arrangements for flooding magazines which are normally present.

(c) Land.

The problem here depends very much on the operational use of the weapon. For example, with long and short range strategic weapons and home-based anti-aircraft weapons, storage can also be isolated and the hazards should not amount to much more than with conventional weapons. For mobile equipment, liquid oxygen and HNO<sub>3</sub> have certain advantages over H.T.P. Liquid oxygen can be produced in situ which simplifies the supply problem, the only other requirement being fuel oil which is readily available since required for other purposes. HNO<sub>3</sub> can be transported in sealed drums, whereas H.T.P. must always be transported in vented vessels.

(d) Air.

The problem of operational supply is similar to that in section 4c, i.e. dependent on whether the aircraft are home-based or not.

5) Hazards.

(a) Explosive Risks.

Both liquid oxygen and HNO<sub>3</sub> are thermodynamically stable whereas H.T.P. is an unstable compound. While this fact must always be borne in mind, it should not be over-emphasised. The Germans carried out many experiments on the explosive behaviour of H.T.P. In general they found that the explosion of bombs in storage tanks containing H.T.P. did not produce detonation. One case of the detonation of a 5 ton storage tank filled with H.T.P. by an oil bomb is however reported in Ref.6. The introduction of foreign matter into H.T.P. may well lead to catalytic decomposition with resultant pressure bursts of storage tanks. This general opinion of the Germans on the relative insensitivity of H.T.P. has been confirmed by work at E.R.D.B. At normal temperatures it has not been found possible to propagate detonation in H.T.P. below 90% concentration except possibly when under very heavy confinement. It is possible that H.T.P. at higher temperatures may be more sensitive but no work, although contemplated, has yet been carried out.

/It



It has been found that emulsions of hydrocarbons in H.T.P. and  $\text{HNO}_3$  will propagate detonation and that such mixtures are sensitive. The provisional view at E.R.D.E. is that the emulsions with H.T.P. are more sensitive than those with  $\text{HNO}_3$ . It is possible that liquid oxygen may form similar sensitive mixtures but no definite information is yet available. Solutions of organic material in H.T.P. will also propagate detonation, the amount of organic impurity required being quite small, e.g. approx. 5% Ethyl Alcohol. Again it is possible that  $\text{HNO}_3$  may behave similarly, but information is lacking. A comparison of the relative hazards of oxidants with (a) self-igniting and (b) non-self-igniting fuels has been given in Ref.7., but there is still not enough information for a firm opinion.

In our present state of knowledge it seems fair to say that H.T.P. in weapons offers greater explosive risks than  $\text{HNO}_3$  but that the difference is probably not very great. Finally, it should be mentioned that in one case H.T.P. injected into a tray of burning petrol produced a violent explosion whereas  $\text{HNO}_3$  under similar conditions, did not. The author does not know whether fires with liquid oxygen have ever led to detonation.

#### (b) Fire.

The risk is considerable with all three oxidants and fires may be initiated spontaneously with H.T.P. and  $\text{HNO}_3$ , and possibly under certain unlikely conditions, with liquid oxygen, e.g. with finely divided metals. The risk is greatest with H.T.P. as the decomposition is catalysed by so many substances, i.e. quite a small amount of impurity may initiate a fire. Each oxidant has its own particular disadvantages, viz: the fire may cause the explosive decomposition of H.T.P. with consequent spreading of the area of inflammation;  $\text{HNO}_3$  will give large quantities of toxic oxides of nitrogen and  $\text{HNO}_3$  vapour, and some metals burn in liquid oxygen once a fire has been started. Fires with  $\text{HNO}_3$  and H.T.P. can be put out by water, but water has less effect on liquid oxygen fires as the water does not dilute the oxidant. Since  $\text{HNO}_3$  gives rise to oxides of nitrogen which are extremely toxic (the effect is often delayed and people inhaling these gases should receive immediate medical attention), it is necessary for gas-masks to be used which makes fire fighting more difficult. In the event of an aircraft crashing with any of the three oxidants, the risk of fire will be very high and in our present state of knowledge, it is impossible to say which one presents the greatest danger.

#### (c) Toxicity.

None of the three oxidants under discussion is toxic but Nitric Acid can be, either in fires or by contamination with certain metals and organic materials which give rise to poisonous gases. They can all cause burns and those from  $\text{HNO}_3$  are certainly more dangerous than from H.T.P. and liquid oxygen. These oxidants should be handled only by properly trained personnel wearing suitable protective clothing. In addition, gas masks should always be available when handling Nitric Acid.

It should be noted, however, that leakage of Nitric Acid is readily detected, which is not the case with H.T.P. and liquid  $\text{O}_2$ .



## 6) Requirements for individual weapons.

### (a) Long Range Strategic Weapons.

These would be used only for carrying very valuable pay loads and it may be that long range bombers are more practicable than these weapons. As such weapons would have multi-stage propulsion it would be possible to use any of the oxidants under discussion, but as the greater part of the trajectory would be outside the earth's atmosphere (i.e. 'drag' would be negligible during most of the journey), systems with the highest possible Specific Impulse are favoured, and liquid oxygen (possibly with liquid hydrogen as fuel) is the best oxidant for this purpose. Liquid fluorine/liquid hydrogen appears to be the ultimate goal.

### (b) Short Range Strategic Weapons.

By these are meant weapons of the type of the German V.2. The usefulness of such weapons depends on the success of anti-aircraft weapons against high flying bombers. The density of the propellant is an important factor and it has been shown (Refs. 8 and 9) that both  $\text{HNO}_3$  and H.T.P. are better than liquid  $\text{O}_2$  on this basis. There is little difference, however, between  $\text{HNO}_3$ /kerosine and H.T.P./kerosine (Ref.4),  $\text{HNO}_3$  being equivalent to H.T.P. containing 88%  $\text{H}_2\text{O}_2$  on a volume basis.

H.T.P. has one advantage by virtue of the fact that it can be catalytically decomposed in a controlled manner, and can therefore be used as a gas producer to actuate auxiliary equipment, such as turbine-driven pumps. There are, however, other gas producing systems, e.g. Messrs. I.C.I. are developing gas producers based on organic nitrates, and nitromethane has been similarly used by the Aerojet Engineering Corporation in America (Ref.10). Solid gas producers have also been developed, e.g. cordite, and the catalysed decomposition of Ammonium Nitrate and Guanidine nitrates. Systems based on the latter can be designed to give very long times of burning and gases at relatively low temperatures - as low as  $500^\circ\text{C}$ .

### (c) Anti-aircraft weapons.

We shall consider land (or ship) to air weapons. These can either be guided or unguided. The unguided weapons will be small (on economic grounds large A.A. weapons must be guided) and their advantage over conventional gun-ejected missiles is that they can reach greater heights and in a shorter time. The Specific Impulse is more important than the performance per unit volume (for small differences in density), but it is clear that liquid oxygen is not suitable, because (a) it is very wasteful to fill small tanks with liquid oxygen and such tanks require frequent topping up, (b) the tank must be heavily lagged to reduce evaporation losses and to prevent freezing of the fuel. Experience with L.O.P./G.A.P. has shown that if the filled weapon stands too long, failure of some of the valves occurs. This is probably due either to water condensation or to changes in dimensions. The weight of the weapon would be excessive. Moreover, firing could not take place at a moments notice which defeats the main purpose of the weapon. Recently A.D.E. have developed an A.A. unguided 4" liquid propellant rocket as a test vehicle (based on the German Taifun) which has behaved satisfactorily in free-flight trials. The propellant system used is the self-igniting propellant combination of W.F.N.A. as oxidant and a mixture of furfuryl alcohol and aniline (70/30 by volume) as fuel. The weight of oxidant is just 14 lbs. and that of fuel is 7 lbs. The volume of oxidant is just over 4 litres, i.e. the

/oxidant



oxidant tank is of about 5 litres capacity and the fuel tank is the annulus between the oxidant tank and the skin of the projectile, which is a compact design.

These arguments exclude the use of liquid oxygen. Nitric Acid is preferred to H.T.P. on the grounds that the oxidant tank can be sealed; thus the weapon can be stored ready for use and easily transported.

For large A.A. guided weapons the density advantage of  $\text{HNO}_3$  and H.T.P. referred to in Section 6(b) is valid as the trajectory of the weapon will be inside the earth's atmosphere. Again,  $\text{HNO}_3$  seems preferable to H.T.P. as it can be stored in sealed tanks. This is a particular advantage on board ship as it means that handling of the oxidant can be done at shore bases. If additional safety is required the weapon can be transported and stored without the fuel. As this will probably be kerosene, it adds no additional supply problem. Further, the main disadvantage of  $\text{HNO}_3$  i.e. evolution of acid fumes and, in contact with many materials, of oxides of nitrogen, results in leakages being readily detected, whereas H.T.P. resembles water in its appearance and absence of smell.

(d) A.T.O's.

A detailed review of the use of the three oxidants for this purpose is given in Ref.3. The main requirements are stated to be (a) Dependability, (b) Simplicity and robustness, (c) Safety in case of a crash and (d) that the propellant should be cheap, readily transported and stored, available in all parts of the world and easy to handle under Service and commercial conditions.

Broadly speaking, the Specific Impulse of the propellant system is not of great importance as the weight of the propellant will in every case be only a small fraction of the total all-up weight of the aircraft and, further, will not be carried when the aircraft is in flight. On these grounds the authors of Ref.3 have recommended the "cold" H.T.P./solid catalyst system. Such a system certainly fulfils requirements (a) and (b) and will be safer in a crash than a propellant based on oxidant and fuel. The consumption of oxidant in this system will however be 50% - 60% higher than the total propellant required in the case of a bicomponent propellant system.

If, however, a bicomponent propellant is chosen, none of the three oxidants shows any particular advantage except in regard to requirement (d) where Nitric Acid may be preferred on grounds of cheapness and ease of storage and transport; liquid oxygen can be produced cheaply in situ. Thus it is difficult to reach a decision without operational experience.

(e) Aircraft Boosts.

This question was also discussed in Ref.3 and the following requirements were specified :-

- a) High performance - large power output for minimum weight of propellant.
- b) Dependability.
- c) Safety - the boost must not greatly increase the risk to the crew in air fighting or in crash landing.

/d)



d) The same propellant requirements as for A.T.O's.

These are clearly desirable properties but, in the author's opinion, it seems certain that the carrying of a liquid propellant system will very considerably increase the risk in air fighting and in crash landing and that this will always be so with the propellants under discussion.

The boost is required to give an interceptor plane a very high rate of climb and a power reserve for interception when at altitude. The use of liquid oxygen is unsatisfactory for two reasons. Firstly, the tank will require considerable lagging to cut down evaporation losses, and also to protect aircraft controls from freezing. This will increase the bulk and weight of the oxidant tank. Secondly, an interceptor plane will have to stand ready for operational flying for considerable lengths of time. This will involve supervision of the oxidant tank in order to see that the evaporation losses are replaced and should the plane not be used it will be necessary to empty the tank or to leave it filled with liquid oxygen. Both procedures are wasteful. Filling with  $\text{HNO}_3$  or H.T.P. are both quicker processes than filling with liq.  $\text{O}_2$ . In view of these comments it seems that either  $\text{HNO}_3$  or H.T.P. are better suited for this purpose than liquid oxygen.

f) Underwater Propulsion.

For submarine propulsion H.T.P. is clearly superior to either  $\text{HNO}_3$  or liquid oxygen. In fact, there is no choice, as a gas producer is required. Similarly, with torpedoes, it is clear that liquid oxygen is impracticable and  $\text{HNO}_3$  with any fuel will leave a bubble track as it contains nitrogen.

7) Availability.

A logical way of discussing this question is to try to form an estimate of the possible requirements per year. Inevitably this estimate is very approximate but it will at least enable some conclusions to be drawn.

The Table at the end of this report gives an approximate estimate in most cases for 1951 of the quantities of oxidant which might be required for the various purposes which have been discussed. It is based on H.T.P. merely because it has been the custom to consider H.T.P. as the main alternative to liquid oxygen. As the figures can be applied to the other oxidants without changing the orders of magnitude of the quantities involved, it has not been considered necessary to add modified estimates for either  $\text{HNO}_3$  or liquid oxygen, particularly as in some cases liquid oxygen is not a practicable proposition.

The Table shows that if all requirements are met by H.T.P., 10,000 to 20,000 tons per annum will be needed for underwater propulsion, and at least 5,000 tons for all other purposes. At present Messrs. Laporte are producing about 500 tons of H.T.P. per year and there are plans for a factory to produce 2,000 tons per year (Ref.1). Plant is also available in Germany but whether this can be removed to the U.K. is a political question and therefore will not be discussed further. Thus, as far as the author is aware, there is not enough production planned to meet even the Naval requirements and as there is no alternative to H.T.P. for underwater propulsion, as there is for other purposes, it is quite clear that the Naval requirements would have to be satisfied before other requirements could be met.

at the rate of



We shall now enquire whether a minimum peace-time requirement of 5,000 tons per annum could be met by  $\text{HNO}_3$  or liquid oxygen. There are many liquid oxygen plants in the country and an extra requirement of 100 tons per week could almost certainly be met, notwithstanding the increasing demands of industry. Further the industrial demands for liquid oxygen are continually increasing so that the liquid oxygen industry has been continually expanding its production capacity.

During the war the total U.K. production capacity of 98%  $\text{HNO}_3$  was fully employed and thus there is clearly a question of competition for various purposes. It has been suggested in Ref.1 that, as each guided missile, for example, would require many times the amount of  $\text{HNO}_3$  needed for conventional weapons (e.g. as cordite), the relative efficiency of these weapons must be assessed. This argument seems false to the author as liquid propellant weapons are intended for use against aircraft flying in the stratosphere at very high speeds, for which purpose conventional weapons are useless. There is thus no question of relative efficiency; rather the efficiency of conventional weapons is zero against such targets.

The author understands that during the war the production of 98%  $\text{HNO}_3$  in the U.K. was a few thousand tons per week. Thus a requirement of 100 tons per week could be met without difficulty even with the plant still available.

As the basic materials for all three oxidants are very cheap (in the case of liq.  $\text{O}_2$ , the cost is nil), the price of the product is an indication of the power, labour and production difficulties. The following figures are quoted from Ref.3, viz: liquid oxygen - £23 per ton,  $\text{HNO}_3$  - £25 per ton and H.T.P. about £192 per ton.

## 8) Conclusions.

The result of this discussion can be summarized as follows but the items must be read in conjunction with the main text.

i) Availability. The quantities of  $\text{HNO}_3$  and liquid oxygen required could be met easily from existing production facilities. In the event of an emergency probably all the H.T.P. produced would be wanted for Naval purposes. The existing production position of H.T.P. in the U.K. is very unsatisfactory indeed.,

ii) Performance. The values are so close that they would not be a deciding factor, except with liquid hydrogen as fuel.

iii) Storage and Transport. All three oxidants can be transported and stored by well established methods. Storage and transport is simplest for  $\text{HNO}_3$ . Liquid oxygen has the advantage that it can be manufactured away from production centres in small mobile plant at present under development.

iv) Explosive Risks. These are greatest with H.T.P. and probably least with liquid oxygen.

v) Fire Risks. Spontaneous fires would originate most easily with H.T.P. but the risk is present with  $\text{HNO}_3$  and liquid  $\text{O}_2$ . Fires with H.T.P. and  $\text{HNO}_3$  can be fought with water, whereas it is much more difficult to fight liquid oxygen fires; metals burn readily in liquid oxygen.



vi) Toxicity. Nitric Acid is the most unpleasant to handle, both on account of the severe burns which it can cause and because of the production of toxic gases in fires and with many materials. Gas masks must be available.

Of the three oxidants, only nitric acid can be used in sealed weapons, an advantage which tends to offset and to minimise the toxicity risk. Moreover, leakage of nitric acid, unlike the others, is readily and immediately detectable.

vii) Use in Weapons.

a) Long Range Strategic Weapons. Liquid oxygen is preferred to H.T.P. and  $\text{HNO}_3$ .

b) Short Range Strategic Weapons. Both H.T.P. and  $\text{HNO}_3$  would be better than liquid oxygen.

c) Anti-Aircraft Weapons.  $\text{HNO}_3$  preferred because sealed tanks can be used which simplifies handling and storage problems and meets the requirement for ready-to-use projectiles most simply.

d) A.T.O's. "Cold" H.T.P. systems offer distinct advantages in simplicity of design, safety and dependability. If bicomponent systems are considered necessary, all three oxidants could be used, but  $\text{HNO}_3$  and liquid oxygen are much cheaper and liquid oxygen can be produced in situ.

e) Aircraft Boosts.  $\text{HNO}_3$  or H.T.P. are preferred to liquid oxygen but the same comments as on A.T.O's are equally applicable.

f) Underwater Propulsion. There is no alternative at the moment to H.T.P.

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Physical Properties of Oxidants.

Oxidant Property	Liquid Oxygen	HNO <sub>3</sub> W.F.N.A.	H <sub>2</sub> O <sub>2</sub> (H.T.P)
Density (gr/ml)	1.14	1.51 (98%)	80% 1.34 (20°C) 85% 1.37 " 90% 1.39 "
Freezing Point.	-218°C (-360°F)	-42°C (-44°F)	80% -22°C (-8°F) 85% -16°C (+3°F) 90% -11°C (+12°F)
Boiling Point.	-183°C (-297°F)	+86°C (187°F)	152°C (306°F) (100%)



TABLE

<u>Purpose</u>	<u>Number of Weapons</u>	<u>Quantity of H.T.P. required per annum in 1951</u>	<u>Comments</u>
1) Long range strategic weapons			No information, but unlikely that H.T.P. would be used. The requirements would not be large.
2) Short range strategic weapons			No information.
3) Unguided A.A. weapons.	If used, large quantities required e.g. 100,000 (a)	Approx. 500 tons	This is probably a gross under-estimate. The requirement per week may be as great as this.
4) Guided A.A. weapons	Seaslug 3,000 Red Heathen (3,000 (b))	500 tons 500 tons	
5) Aircraft A.T.O.	1,000 (a)	500 tons	1000 lbs. H.T.P. per launch to give thrust of 7000 lbs. for 30 secs. If "cold" A.T.O. requirement about 50% higher.
6) Aircraft Boost.	1,000 (a)	3,000 tons	3 tons per flight requiring 4,000 lbs. thrust per 6 mins. at full throttle.
7) Underwater Propulsion		10,000 tons 20,000 tons	The author has seen quoted figures of 8,400 tons and 20,000 tons.

a) This figure is chosen merely to show that the oxidant requirements for this type of weapon are comparable with those for guided weapons. The figures are probably gross under-estimates.

b) The figure is chosen by analogy with that for Seaslug.



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**ABSTRACT:**

An investigation was made of the general suitability of the three oxidizers - liquid oxygen (lox),  $H_2O_2$ , and  $HNO_3$  in British liquid rocket-propellant systems for operational use. The investigation is concerned with the availability, performance, storage, transport, explosive and fires risks, toxicity, and use in weapons of these three oxidizers.  $HNO_3$  and lox required could be met from existing production facilities, whereas the production position of  $H_2O_2$  is very unsatisfactory in England. The performance values of all three oxidizers are very similar, except with liquid hydrogen as propellant. All three oxidizers can be transported and stored by well-established methods. Explosive risks are greatest with lox and  $HNO_3$  has the greatest toxicity. All three oxidizers can be used in guided missiles and in ATO- and booster-engines. At the moment, only  $H_2O_2$  is considered suitable for underwater propulsion.

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